SOILS AND BACTERIA.*

By LYMAN C. WOOSTER, Ph. D., State Normal School, Emporia.

OWING to the inexact forms of statement used by many writers, most people believe that plants use as foods certain minerals found in soils, while animals eat organic materials found in plants and other animals. Any one who knows aught of the needs of plants and animals and of the nature of foods knows that plants and animals must both have for their tissues and activities starch, sugar, oils, and proteids; and that no plant, except a few bacteria, can get energy and tissue foods directly from the mineral world. Water, carbon dioxid, potassium and sodium nitrates, ammonia in some form, sodium chlorid, calcium sulfate (gypsum), magnesium sulfate (epsom salts), calcium phosphate and some soluble compound of iron are merely the crude materials out of which green plants, in the presence of sunlight or the light of the electric arc, build their foods, such as starch, oil, and the proteids. The minerals named above are crude food materials, and are foods in no other sense; but their presence in soils is as necessary to complex plants as are brick, mortar and lumber to the house-builder.

The amount of these crude food materials used by a crop of wheat, for example, is surprisingly large. From a single farm of 160 acres, where exclusive wheat farming is followed, there is an annual waste of fertility equivalent to 28,500 pounds of nitrogen, 5000 pounds of potash, 3000 pounds of phosphoric acid, and 1600 pounds of lime. Unless these minerals are returned to the soil, the land must continue to diminish in productiveness till it finally becomes barren. This was the fate of the old tobacco plantations of old Virginia, and is soon, certainly within fifty years, to be the result of continuous wheat cropping in Kansas without the use of fertilizers.

The humus and bacteria of the soil are most directly concerned with its nitrogen content, and it is to these elements of fertility that I wish to address myself.

It is very unfortunate for the farmer that no cultivated plant can use uncombined nitrogen as a crude food material, for the atmosphere is four-fifths nitrogen. The nitrogen used by plants

*In preparing this paper I have freely used the observations and experiments described in two standard works, "Bacteria," by Geo. Newman, published by G. P. Putnam's Sons, and "Physics of Agriculture," by F. H. King, published by author, Madison, Wis., together with my own personal observations and experiences. These have served as the bases of the inductions, which I trust will be of some service to the farmers of our state.— L. C. W.

large enough to be seen by the unaided eye must be in the form of a nitrate, such as Chili saltpeter or common saltpeter, or possibly in some salt of ammonia.

Could cultivated plants use atmospheric nitrogen directly, the chief problem of soil fertility would be solved. More than 33,000 tons of nitrogen rests on each acre of ground. Contained in Chili saltpeter, this amount of nitrogen would be worth $4,000,000 per acre, and the supply would be inexhaustible. So far as is now known, bacteria alone, of all plants, can use nitrogen and the nitrites as crude mineral foods. Fortunately they excrete the substances as nitrates. The higher plants then absorb the nitrates and the other mineral food materials and prepare the various proteids to increase their cell protoplasm.

Soil bacteria are of many kinds; and the number of individuals of each kind, even in a handful of soil, is almost beyond comprehension. One gram (one-fourth teaspoonful) of virgin soil contains 53,436 bacteria; and the same amount of soil from a cemetery supports 363,411 bacteria. Few are found below a depth of six feet. Their rate of increase in numbers through cell division is equally remarkable. Milk fresh from the cow contains on the average 15,000 bacteria to the cubic centimeter (one-fourth teaspoonful); milk four hours old has in the same volume 100,000 bacteria, fifteen hours old, 6,000,000, and ten days old, 1,000,000,000 of these remarkable plants.

Though the systematic study of bacteria is less than a half a century old, and though each species varies in form and activity through wide limits, in a few hours, in different environments, 600 or 700 kinds have been named and described. These kinds may be grouped, for the purposes of this paper, in five or six classes:

1. The bacteria of putrefaction.
2. The air-hating, denitrifying bacteria.
3. The air-loving, nitrifying becteria.
4. The nitrogen-fixing, root-tubercle bacteria.
5. The pathogenic bacterta.

1. The bacteria of putrefaction reduce the bodies of plants and animals to the condition called humus in soils. The complex organic compounds are broken down, resulting in a release of energy and much cell-substance material for the bacteria and in the evolution of various gases, such as carbon dioxid, dihydric sulfid, ammonia, and probably some nitrogen. However, the work of these bacteria seems to be necessary in order that organic matter

may be reduced to a usable condition. Among these bacteria are: *Bacillius colli*, *B. mycoides*, *B. mesentericus*, *B. liquidus*, *B. prodigiosus*, *B. ramosus*, *B. vermicularis*, *B. liquefaciens* and many members of the great family of *Proteus*.

2. The air-hating, denitrifying bacteria are responsible for the more or less complete destruction of the nitrates in the farm and commercial fertilizers, when these are buried in such a way that air is largely excluded. They also do an important work in assisting the bacteria of putrefaction in destroying excrement in cesspools and retention vats, where sewage is detained for work of this character. These bacteria work best where the supply of air is limited and the amount of organic matter great. The organic matter is oxidized with oxygen taken from the nitrates; and a distinct rise of temperature results, as may be seen in heaps of manure. Much nitrogen, consequently, is lost to the manure and soil. Among the denitrifying bacteria that have been isolated are: *Bacillus fluorescens non-liquefaciens*, *Mycoderma ureæ*, and some of the *Staphylococci*.

The very effective character of the work done by the putrefactive and denitrifying bacteria was proved by the late Colonel Waring, the eminent sanitary engineer. He kept two tons of dry earth for use over and over in dry-earth closets. The closets were emptied once in two months in heaps on the floor of a dry cellar. This material was used, in all, about ten times, and then the material was analyzed for the amount of nitrogen it contained. It was found that 4000 pounds of the soil had only eleven pounds of nitrogen, though at least 230 pounds had been added to it and it contained three pounds at first.

It would seem, then, from this and other experiments, that farm manure would better be spread in layers, in the barn-yard, a few inches thick, till it is somewhat decomposed, and then spread thinly over the fields and not plowed in deeply, unless the surface can be frequently cultivated, so the air can have free access to every portion of the soil containing the fertilizer. In this way the air-hating bacteria will be deterred from working in the fertilizer overmuch.

3. The work of the air-loving, nitrifying bacteria beautifully complements that of the denitrifying bacteria, if they are given a fair chance. As their name implies, they work best in loose soil near the surface of the ground, and are nearly absent from soil at a greater depth than two feet. They are of several kinds, and are very numerous in rich, porous humus. Some change ammonia to nitrites, and others change nitrites to nitrates. They do not work

in acid soils, nor in soils strongly alkaline, but do best in soils faintly alkaline. Acid soils must be neutralized by alkaline earths, such as quicklime and wood ashes; alkali spots should be sanded and drained, or crude sulfuric and nitric acids may be sprinkled over such places.

The air-loving, nitrifying bacteria work on the surface of sewage in the retention vats, and very vigorously when it has been passed out into small, open fields, where the sewage may stand a few days, spread out in a stream a few inches thick. The bacteria reduce organic matter unreduced and oxidize the ammonia, nitrites, and sulfites. When this work has been completed, the sewage is ready to be used as a fertilizer.

The nitrifying bacteria use various organic matters (of which phosphates are essential constituents) as foods, though the remarkable fact has been discovered that the nitrifying organisms can develop and perform all their functions on inorganic materials. They have the power to live and grow in a medium consisting solely of acid carbonates of sodium and calcium in an ammoniacal solution undergoing nitrification. No other plants destitute of chlorophyll can do this.

The nitrous bacteria have been named *Nitrosomonas* and *Nitrosococcus*, and the nitric organism the *Nitrobacter*. These are evidently most valuable to all farm crops, as without them the soil would soon become barren.

4. The root-tubercle bacteria are recent discoveries. For a long time it has been known that the clovers, peas, beans and other legumes not only do not exhaust the soil, but even leave it in better condition than before the crop was grown. Certain tubercles on the roots of these plants are crowded with bacteria which are now known to possess the power to use the free nitrogen and oxygen of the air in preparing those compounds of nitrogen that serve as crude food materials to the host-plants. The mutual relation existing between the legume and the bacteria is not well understood, but there is no question as to the benefit accruing to the host.

Certain companies are now preparing cultures of bacteria, appropriate for use on the several crops of legumes, to sell to farmers and gardeners. The Western Nitrogen Culture Company, of Topeka, prepares packets of bacteria and food, to be used on sixteen important legumes, one packet for each kind. The tubercle bacteria do not thrive in acid or strongly alkaline soils, but in average Kansas soil they multiply rapidly, and their excretions in the tubercles cause a greatly increased growth of the legume and at

the same time help to enrich the soil. These bacteria, beyond question, increase the growth of alfalfa and Red clover. Indeed, it is largely because of their presence in the soil that these crops continue to flourish in Kansas.

The root-tubercle bacteria are air lovers, and the soil must be kept loose by cultivation or kept well shaded by the crop when wet, or alfalfa, clover and the other legumes will not make their best crop. Dressings of land plaster (gypsum) help these plants wonderfully, but a porous soil is of the first importance.

In the best soils the pore space equals one-half the volume of the soil. In clay soils it is more; in sandy soils, strangely enough, it is less. As pore space is either air space or water space, the importance of thorough water drainage, both surface and subsoil, is evident. When the pore space is filled with air, the air-loving, nitrifying bacteria and the root-tubercle bacteria flourish best and the heaviest crops are harvested. When the pore space is largely reduced by plowing when the soil is too wet, or is filled with flood-water, the air-hating, denitrifying bacteria rob the soil of its nitrates, and light crops are harvested. Puddled soil may be excellent for dirt roads—indeed, makes the best roads when quickly dried, with the pore space absent or largely reduced—but, on the farm, it cannot grow valuable crops.

5. Pathogenic bacteria are frequently found in rich soils. Among the most numerous and dangerous of these is the bacillus of tetanus (lockjaw). No wound received in stables is a safe wound. The bacillus works in the wound; and lockjaw is caused by its excretions, which are absorbed by the blood and carried to the nerve centers.

The bacteria which cause typhoid fever and tuberculosis are likewise found in rich soils. The germs of typhoid fever may live in soil impregnated with the excretions of a typhoid patient 456 days, and the germs of tuberculosis are found to be alive in soil several weeks after having been added to it. All germs of this character should certainly be destroyed before they are thrown upon soil.

Other disease germs are known to exist in the soil, some of bacteria and others of animals—the protozoa. It is probable that some of the latter get into the drinking water and cause dysentery and, possibly, appendicitis.

The soils about buildings are being studied with the greatest care, and, while very much remains for future work, enough is now known to make it certain that water from deep wells, wells with

cemented walls and situated on highest ground near house, or else boiled water, is the only water safe to drink, if one would escape these deadly diseases.

All that has been given in this paper is in full accord with the rules established empirically by our most successful farmers. The use of fertilizers, the thorough cultivation of the soil and the rotation of crops are the A-B-C's of profitable farming. The one supplies the plants with necessary mineral food elements, the next aerates the soil for the air-loving, nitrifying bacteria, and the last gives time for the rise from the subsoil of the mineral food elements peculiar to each crop.

Any of these three things can be overdone, especially the second and third. Plowing in deeply much coarse material so opens up the soil that the water to a depth hurtful to the crop is wasted. On the other hand, thin surface cultivation, producing a soil mulch, is very beneficial in dry seasons, as the amount of soil thoroughly dried is small, and this thin layer of loose earth stops the water that is rising from the greater depths through capillary tubes. Taking as a standard soil not cultivated, the water saved by a cultivation one inch deep, once a week, was nearly 25 per cent., twice a week, was over 27 per cent.; three inches deep, was 27 per cent. and 32 per cent. for once and twice a week respectively.

Crop rotation is found to be much better for soil bacteria of the helpful kinds than absolute rest. The latter, where there is no cultivation, enables the air-hating, denitrifying bacteria to destroy more fertilizers than the rest brings in from rock, gravel and subsoil disintegration.